

Technical session 2h: Pile foundations (II): Installation, quality control, performance, and case histories

Séances techniques 2h: Fondations sur pieux (II): Installation, contrôle de qualité, performance et études de cas

A. Holeyman

Civil and Environmental Engineering Department, Université catholique de Louvain, Louvain-la-Neuve, Belgium

Y. Kikuchi

Port and Airport Research Institute, Japan

1 INTRODUCTION

The session was started at 10:30 on September 15, 2005 by the Chairman who first presented the proposed session program to approximately eighty participants. After consideration of key ideas for the discussion amongst the General Reporter and Panelists, the Discussion Leader suggested the following discussion topics:

- Pile performance with respect to Installation (modelling, monitoring, case histories)
- Pile performance as demonstrated by Testing Methods
- Consolidation of Knowledge (Data Bases, Experience Bases, Value Bases)

The timing for each of the main portions of the session were set as follows:

- 5 min introduction by Chairperson
- 30 min General Report
- Total 55 min of Panelists' presentations
- 25 min floor discussion
- 5 min Closing remarks by Chairperson

Following the presentation of the General Report by B. Lehane, panelists were announced as follows to address the corresponding topics:

- *M. Bustamante (France)* - Polymer slurry - *Bored piles*
- *D. White (UK)* - Jacked Piles - *Installation*
- *J. Seidel (Australia)* - High strain dynamic pile testers (*narrative distributed in the absence of Panelist*)
- *A.F. Van Tol (Netherlands)* - CPT based design – *CFA Piles*
- *E. Caputo (Italy)* - Experimental evidence - *Testing*
- *M. Bottiau (Belgium)* - TC18 Pile Matrix – *Knowledge & Case Histories Consolidation*

A lively discussion then took place, fed by questions from the floor to the panelists, between panelists, and even directly between attendees. The session had to be closed at 12:30 to allow the conduct of the 2001-2005 General meeting of the ISSMGE Technical Committee 18 on Deep Foundations, starting at that time. The Chairman thanked all involved and paid tribute to the excellent preparatory work assumed by Y. Kikuchi, Session Technical Secretary.

Hereafter follows written contributions from the panelists who felt strong documenting the points that were raised during the discussion and from the Discussion Leader. References from all have been regrouped under a single heading at the end of this discussion compendium.

2 RE-DESIGN BASED ON CPT'S PERFORMED AFTER PILE INSTALLATION, BY PROF. A. F. VAN TOL

Professor Van Tol, of the Delft University of Technology, addressed the issue of using CPT data collected in the close vicinity of installed piles with a view to incorporate installation effects into their design.

CPT based design of pile foundations is a generally accepted method in areas where Cone Penetration Testing is a standard soil investigation technique. The so-called direct CPT method proved its usefulness and reliability. Several National codes in Europe apply this direct CPT method to determine the pile capacity (Cock & Legrand, 1997).

The calculation procedures in different countries, like the Dutch, the French or the Belgium method are quite similar. They distinguish between shaft and base capacity and determine the shaft and base resistance directly from the cone resistance, applying different empirical factors:

- installation factors for the effect of pile installation and the soil type
- geometrical factors

Re-design based on CPT's after pile installation (with installation factors equal to 1.0) may be beneficial and is allowed in some design codes. For displacement piles in dense groups the significant compaction may be taken into account in a re-design. For Bored and CFA piles the installation factors in the codes are in general on the safe side to cover the uncertainties of the installation process. Therefore a re-design based on CPT's after an optimal installation process may lead to a more cost effective design.

There is no standard procedure for such a re-design. This contribution tries to answer the following questions regarding such a procedure:

1. How many CPT's should be performed?
2. At what distances from the pile?
3. In one line or around the pile?
4. Which of the CPT's finally leads to the representative pile capacity?

To answer the first three questions the effect of the distance between the CPT's and the installed pile and the orientation of the CPT's around the pile was assessed using the results of CPT's performed after pile installation at 10 project sites in the Netherlands, where CFA piles were installed. The results of this study are reported in Hannink & Tol, (2005). It was concluded that the effect of installation is not equal around the pile and that the effect decreases strongly with increasing distance.

To answer the fourth question a study was carried out to link the results of pile load tests to the calculated pile capacity based on CPT's performed after installation at different distances and

around the test piles. Two test sites with in total four test piles were available for this study.

At one of these test sites three CPT's were performed at almost the same distance but at different sides of the test pile. The CPT's were completely different: one showed an enormous decrease of the cone resistance in relation to the CPT performed prior to pile installation. Two CPT's were similar showing a moderate decrease of cone resistance due to pile installation. Comparing the calculated pile capacity based on each CPT with the result of the static pile load test demonstrated that the CPT with the lowest cone resistance resulting in the lowest pile capacity does not determine the pile capacity. The measured pile capacity was quite close to the average of the three calculated pile capacities based on the three CPT's around the pile.

A resume of the results from the other test site, where CPT's were performed after pile installation at different distances and around the tested pile, is presented in figure 1. The ratio between the calculated $q_{b,after}/q_{b,before}$ and $q_{s,after}/q_{s,before}$ is presented as a function of the distance to the pile. This ratio for pile base and shaft capacity is based on all the CPT's after installation and one CPT before installation. At the vertical axes also the results of the pile load test are depicted. It appears that these values can be predicted rather well with the trends lines based on the calculated ratios for pile base and shaft capacity.

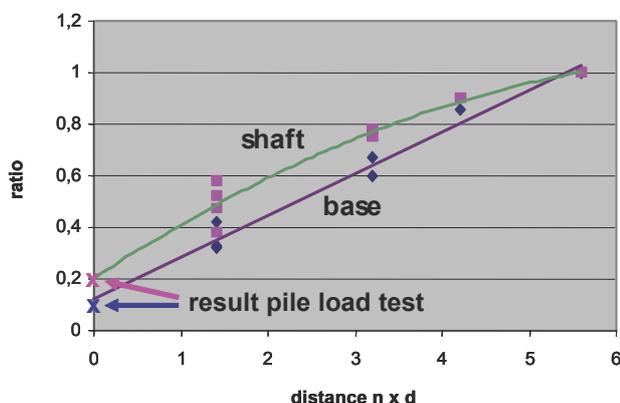


Figure 1. Ratio between the calculated $q_{b,after}/q_{b,before}$ and $q_{s,after}/q_{s,before}$ as function of the distance to the side of the pile and values from the static pile load test.

It was concluded that:

- A re-design based on CPT's after pile installation can be beneficial, in particular in case of projects with large numbers of piles;
- For piles with soil excavation a re-design should be based on CPT's, performed at different distances and around an installed pile;
- The Re-design may be based on the average capacity based on CPT's after installation around the pile, taking distance effects of installation into account.

3 AXIAL RESPONSE OF JACKED PILES, BY DR D.J. WHITE,

Dr David White, of the University of Cambridge, presented some recent research into the axial response of jacked piles. Increasingly stringent environmental legislation precludes the use of pile hammers in urban areas, and restricts the disposal of spoil created by the construction of conventional bored piles. In response, there has been a proliferation of new construction methods for pile foundations. One such new construction technique is pile jacking. High-capacity pile jacking machines have recently been developed in Japan, China and the UK. These machines operate by pushing the pre-formed pile (made from steel

or precast concrete) into the ground with hydraulic rams, using static force alone. In the case of the 'press-in method', developed in Japan, reaction is provided by gripping the heads of previously-installed piles (Figure 2). The largest 'press-in' pile jacking machines have a capacity of ~4 MN and can install piles with a diameter of up to ~1.8 m in strokes of length ~1 m.



Figure 2. A 'press-in' piling machine for installing large tubular piles

Dr White presented a series of field tests on small (diameter, $D = 100$ mm) jacked piles and pile groups installed at a sandy site, located in Takasu, Kochi-city, Japan. These tests are reported in more detail elsewhere in the conference proceedings (Deeks et al 2005). The key observation from these tests was the stiff load-settlement response. The single piles reached plunging failure at a settlement of 3 mm (3% D). The capacity at failure was well-predicted by the MTD/IC design method (Jardine & Chow, 1996), modified with an ultimate base resistance equal to the cone resistance ($q_{bf} = q_c$), and this capacity was equal to the jacking force applied at the end of installation.

This high axial stiffness was attributed to the pre-loading of the soil below the base during installation, and the presence of residual base load. The stiffness exceeded typical recommended design stiffnesses for driven and bored piles by factors of more than 2 and 10 respectively. Since pile design is usually governed by serviceability and stiffness, these results suggest that jacked piles offer the potential for significantly improved design efficiency.

The load-settlement response of the single piles was well predicted by load-transfer back-analysis with parabolic τ_c - z and q_b - z models using the RATAZ software (Randolph 2003). Good agreement between the measured and calculated head response was found when the parabolic τ_c - z response was based on an initial stiffness of $G_0/2$ (where G_0 was found from q_c following Baldi et al (1989)) and the base response was fully mobilised at a settlement of 3.5% of the pile diameter. The locking-in of residual load was also modelled.

After presenting the results described by Deeks et al (2005), Dr White showed further results from a larger closed-ended pile ($D = 312$ mm) that had recently been tested at the same site, one day after installation by jacking. This pile was equipped with a base load cell, to allow the measurement of residual base load and base stiffness.

This larger pile showed a similarly stiff response, reaching apparent plunging failure at a settlement of ~2% of the pile diameter, with a total capacity of 350 kN and a base capacity of 200 kN (Figure 3). An additional increase in base capacity to 267 kN (whilst the shaft resistance remained constant) was observed as the pile was failed to a settlement of 25% D .

Figure 3 compares the measured load-settlement response with a RATAZ back-analysis using the τ_c - z and q_b - z models previously fitted to the 100 mm pile results. Only the base stiffness

has been changed, from $w_{bf} = 3.5\%D$ to $2\%D$, reflecting the lack of plug compression within this closed-ended pile. This base response corresponds to an initial elastic stiffness of $\sim 1.4G_0$.

A significant residual base load was observed, with a consequent reduction in the settlement required to mobilise the base capacity. The load-settlement response was well-predicted by the RATZ analysis. Since the shaft capacity is under-predicted by the chosen design method, the responses diverge close to failure.

The measured plunging capacity exceeds the installation force by $\sim 5\%$. However, the shaft and base resistances during the load test differed more significantly from the values recorded during installation. At the apparent plunging failure ($2\%D$ settlement), the base resistance was 20% lower than during installation, whilst the shaft resistance was 50% higher. The increase in shaft resistance ('set-up') slightly exceeded the reduction in base resistance ('relaxation'). With further settlement the base resistance recovered the value measured during installation. This relaxation of the base response matches the trend reported for jacked piles by Lehane (2005), but it should be noted that the ultimate (or plunging) value is the same as during installation.

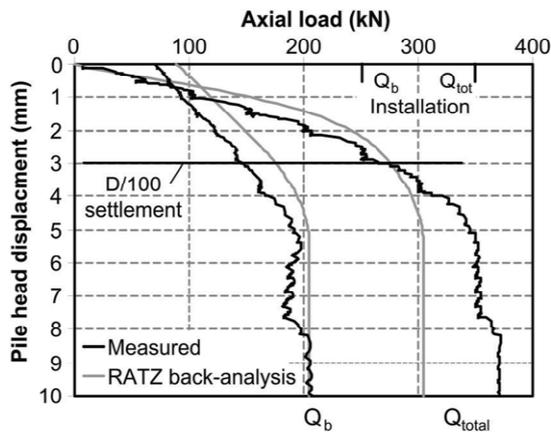


Figure 3. Load test on 300 mm diameter jacked pile

Dr White concluded his presentation by displaying the stiffness response in the load test as the fractional drop in secant pile head stiffness with normalised settlement. In this form, the load-settlement response is converted to the familiar 'S-shaped' stiffness degradation curve that is widely used, with a logarithmic axis, to highlight the non-linearity of soil stiffness with strain, or deformation.

The stiffness degradation from back-analysis of this load test is compared with an equivalent curve derived from a database of bored piles (Berardi & Bovolenta 2005) in Figure 4. The jacked pile is typically 5 times stiffer than the bored pile design line at working settlements. This comparison shows the potentially higher performance offered by jacked piles. As jacked piles become more widely used, more case studies of this kind will allow the relative stiffness of bored and jacked piles to be better assessed. Although comprising only one load test, the comparison presented in Figure 4 suggests that the potential design economies could be significant.

4 BELGIAN RESEARCH ON DISPLACEMENT SREW PILES, BY A. HOLEYMAN

The Chairman has taken the liberty to summarize important results highlighted by recent research efforts conducted in Belgium, stressing the influence of installation effects on the performance of piles, as documented by their load-settlement curves. An overview is thus given of the Belgian research program addressing soil displacement screw piles which was executed in the period 1998-2002, and during which 72 pile load tests have been performed.

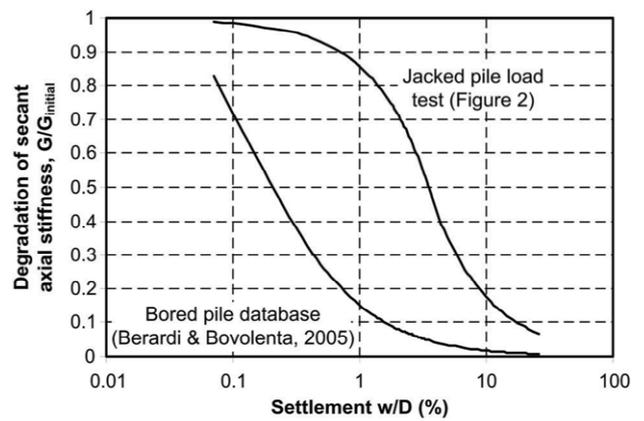


Figure 4. Stiffness decay from back-analysis of jacked and bored piles

In the first stage of the project (BBRI, 1998-2000) 5 types of screw piles and driven precast piles were installed on a site in Sint-Katelijne-Waver (B) where the subsoil consists of O.C. tertiary Boom clay. Pile loading tests were executed on 30 test piles: 12 static load tests, 2 series of twelve dynamic load tests and 6 Statamic tests. The results of this test campaign were extensively reported during the first symposium "Screw piles - Installation and Design in Stiff Clay", which was held on 15 March 2001 in Brussels. The proceedings of this symposium were written in English and are published by Swets & Zeitlinger (Balkema), ISBN 90 5809 192 9, and contain comprehensive details about the test campaign (geologic background, soil investigation program, test results, international prediction event, ...)

In the second stage (2000-2002), a similar extended test campaign was organised on a site in Limelette (B), where the subsoil consists of quaternary silty layers (loam) and tertiary Ledian-Bruxellian sand. The results of the second test campaign have been reported at a second symposium "Screw Piles in Sand - Design and Recent Developments" that took place on 7 May 2003.

Figures 5 and 6 provide a synthesis of the observed installation effects on the tested piles performance at the Sint-Katelijne-Waver and Limelette test sites, respectively. These figures give the "normalized" load settlement curves of the static pile load test. On the horizontal axis the pile settlement is expressed relative to the pile base diameter. On the vertical axis the measured load Q during the pile load test is expressed relative to the value of the reference calculated ultimate pile bearing capacity. These reference calculated ultimate pile bearing capacities have been calculated by means of the semi-empirical calculation methodology based on CPT data as formulated in Holeyman et al. (1997), all the empirical factors have been supposed to be equal to one.

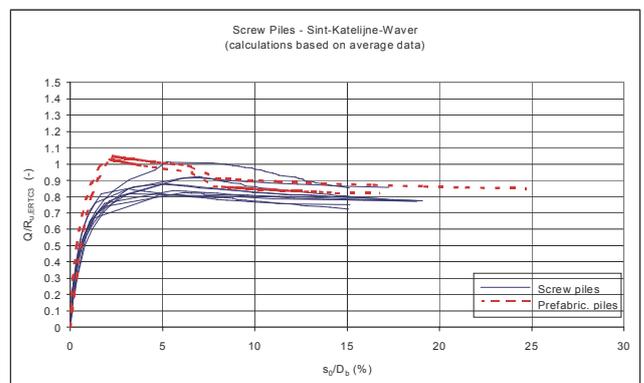


Figure 5. Normalised load settlement curves static pile load tests Sint-Katelijne-Waver

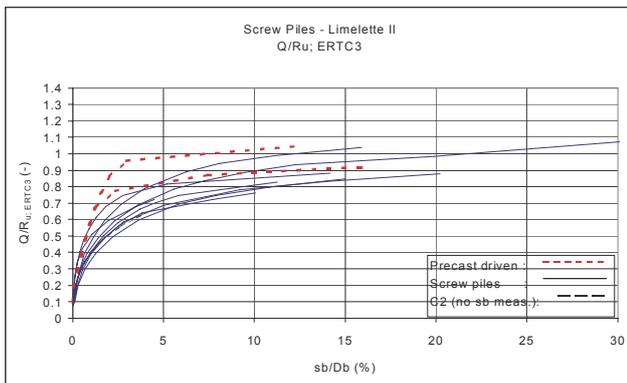


Figure 6. Normalised load settlement curves static pile load tests Limelette

Out of these curves a global empirical factor, that takes into account the pile installation method, the nature of the pile shaft material and roughness, and the soil type can be deduced. If it is supposed that the measured ultimate pile bearing capacity is the load corresponding with a settlement of 10% of the pile base diameter (conventional rupture load), then the global semi-empirical coefficients of Table 1 are obtained.

In Figure 7 the results of the static load tests obtained at the Limelette test site are compared with the results of an earlier test campaign in 1995/1996 on different types of driven displacement piles, e.g. a driven tubular pile, a driven precast pile, and a driven Franki pile with slightly enlarged bottom plate. The global coefficients that can be deduced from Figure 7 for these driven piles are also given in Table 1.

Table 1. Range of global coefficients obtained at the Sint-Katelijne-Waver and Limelette test site

Pile type	Sint-Katelijne-Waver	Limelette
Soil displacement screw piles	0.77 – 0.97	0.76 – 0.97
Driven Precast piles	0.85 & 0.90	0.89 & 1.02
Driven tubular pile – 1995/1996	-	0.79
Driven precast pile – 1995/1996	-	0.90
Franki pile – 1995/1996	-	0.90

For the Sint-Katelijne-Waver test site more details of the results of the static load tests and the comparison of the test results with the semi-empirical calculation methods applied in Belgium are given in Maertens et al. (2001). The results of the dynamic and kinetic load tests were interpreted by Holeyman et al. (2001).

Until now the results of these pile load test campaigns have especially been compared with the design methods based on CPT, which are currently used in Belgium, and are being taken in consideration by the Belgian working group charged with the establishment of the Belgian National Annex of the Eurocode 7. Based on the actual test results it can be concluded that the soil displacement screw pile types have several excellent qualities: the pile installation method is fast, without soil removal, vibration free and the produced noise is limited. In general a good and constant pile quality with depth is obtained and the total pile bearing capacity of soil displacement screw piles is in general close to that of driven piles. Therefore the soil displacement screw piles, which participated at the research project, can be considered as very valuable pile types.



Figure 7. Normalised load settlement curves static pile load tests Limelette including results of an earlier test campaign (1995-1996) on driven displacement piles.

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